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TECHNICAL REPORT BRL-TR-2655

SAFE SEPARATION DISTANCES BETWEEN SAND COVERED CORRUGATED STEEL PIPES CONTAINING EXPLOSIVE CHARGES

Harry J. Reeves

May 1985

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US ARMY BALLISTIC RESEARCH LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Storing ammunition in sand or earth covered pipes would permit tactical units, with limited real estate assets, to construct non-permanent storage sites, quickly and economically, to support maintenance operations requiring downloading and for the storage of selected basic load items.

To provide safety design guidance for such a facility, the Ballistic Research Laboratory sponsored by the Department of Defense Explosive Safety Board, conducted a series of donor acceptor tests employing sand covered corrugated steel

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pipes to determine the safe separation distance between pipes required to localize damage in the event that the ordnance items in one pipe detonate en masse. Steel pipes with diameters ranging from 0.5-2.0 ft. (15-61 cm), two diameters in length, containing explosive charges weighing up to 47.5 lbs (21.5 kg) were used to support this effort.

The results of a regression and discriminant analysis of the test results can be used to either design a new facility or evaluate the safety of an existing facility.

Limited test data are also available on the influence of venting, explosive charge position, top cover depth and the effectiveness of sand-air-sand barriers versus all sand barriers.

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A. Background

The use of separated earth covered pipes, for the non-standard storage of ammunition, has been proposed in the past. The acceptance of such a practice would permit tactical units, with limited real estate assets, to construct non-permanent storage sites, quickly and economically, to support maintenance operations requiring downloading and for the storage of selected basic load items. Unfortunately, the data base required to design such a facility, safely and economically, is inadequate.

To satisfy this data base requirement, in part, the Ballistic Research Laboratory (BRL) proposed to conduct a limited series of donor-acceptor tests employing sand covered corrugated steel pipes and bare explosive charges. The proposal was accepted and funded by the Department of Defense Explosive Safety Board (DDESB).

B. Objective

The primary test objectives were as follows:

1. Determine the minimum distance between sand covered corrugated steel pipes such that when an explosive charge positioned inside one pipe (donor) is detonated, the other pipes (acceptors) exhibit no significant visible sign of blast inducted damage.

2. Compare the relative effectiveness of sand versus sand-air-sand barrier between the donor and acceptor pipe.

II. TEST PROCEDURES

The standard donor-acceptor test setup used in this series of tests is shown in Figures 1 and 2. The explosive charge weight, separation distances between the donor and acceptor pipes, and pipe diameters were systematically varied to experimentally establish safe separation distances, as a function of charge weight and pipe diameter, for the standard test setup.

The setup employed standard commercial grade corrugated steel pipes, two diameters in length, with diameters ranging from 0.5-2.0 ft (15-61 cm) with a wall thickness of 0.0625-inches (1.6 mm). The pipes were separated, covered to a depth of approximately one diameter, and closed on one end with sand.

The explosive charges were positioned near the closed end of the donor pipes. Cast pentolite charges were used for charge weights up to 0.75 lbs (340 grams). Hand packed Composition C-4 charges, 2 through 25 lbs (0.9 through 11 kg) and cast Composition B charges, 47.5 lbs (21.5 kg), were used in the remaining tests.

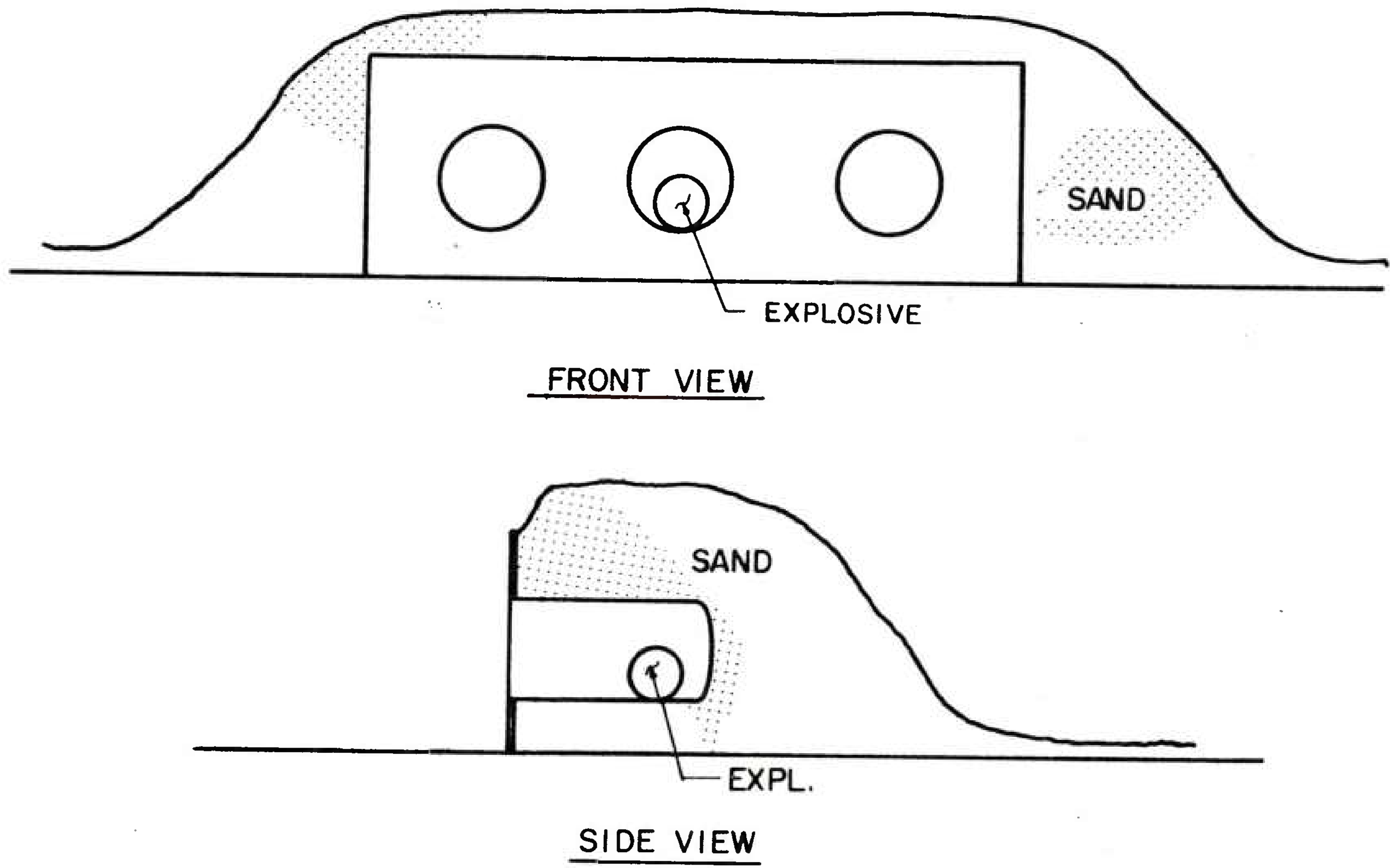


Figure 1. Standard Test Setup

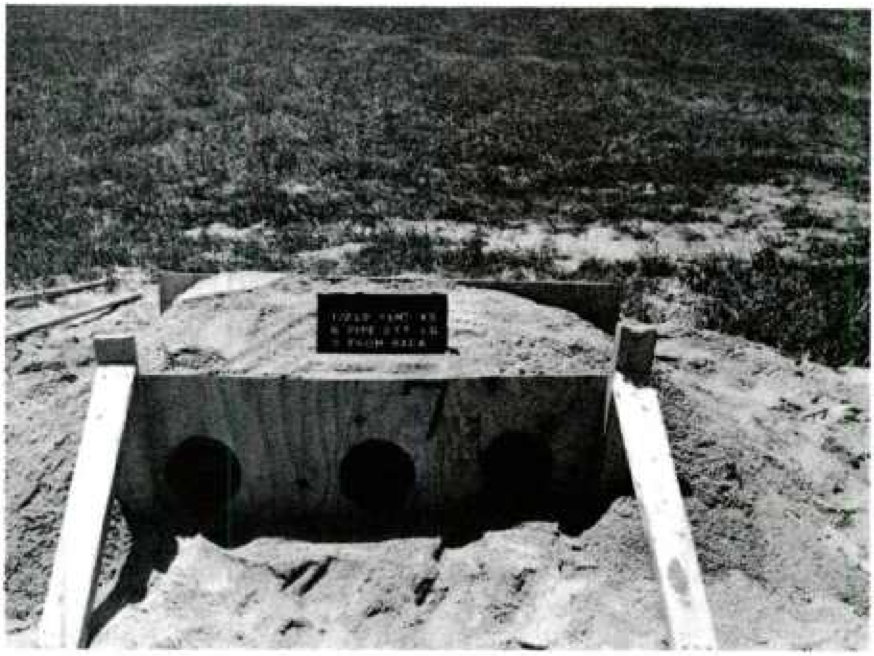


Figure 2. Standard Test Setup

A limited number of additional tests were conducted to investigate the effects of:

1. Positioning the explosive charge in the center of the donor pipe.

2. Increasing the pipe length from two to four diameters.

3. Separating the donor and acceptor pipes with sand-air-sand barriers. See Figures 3 and 4.

4. Separating the normally closed ends of the pipes from the sand barrier to increase venting. See Figure 5.

5. Increasing the depth of the sand cover on top of the pipes from one to four pipe diameters.

6. Positioning four sand filled 155 mm propelling charge cans between the explosive charge and the normally open end of a donor pipe. See Figure 6.

Test results were documented by recording any blast induced deformation at the front (open) and rear (normally closed) ends of the acceptor pipes. This assessment procedure permitted test results to be ranked quantitively for a given pipe diameter.

III. RESULTS & OBSERVATIONS

Test results are presented in Table 1 and Figures 7, 8, and 9. Observations, based on the test results, are discussed in the following sections.

A. Explosive Charge Location

Moving the explosive charge from the center to the normally closed end of the donor pipe changed the location of damage on the acceptor pipes from the center to the normally closed ends, see Tests 7 and 8. As expected, damage to the normally closed ends of the acceptor pipes was greater than that observed at the open ends for all test configurations.

B. Pipe Length

Increasing the length of 0.5 ft (15 cm) pipes from two to four diameters, see Tests 2 and 7, had little or no effect on test results.

C. Sand-Air-Sand Barriers

The performance of the sand-air-sand barriers versus all sand barriers was disappointing. The damage suffered by the acceptors with sand-air-sand barriers was measurably greater than those observed in a similar test with all sand barriers. Compare Tests 12 and 14.

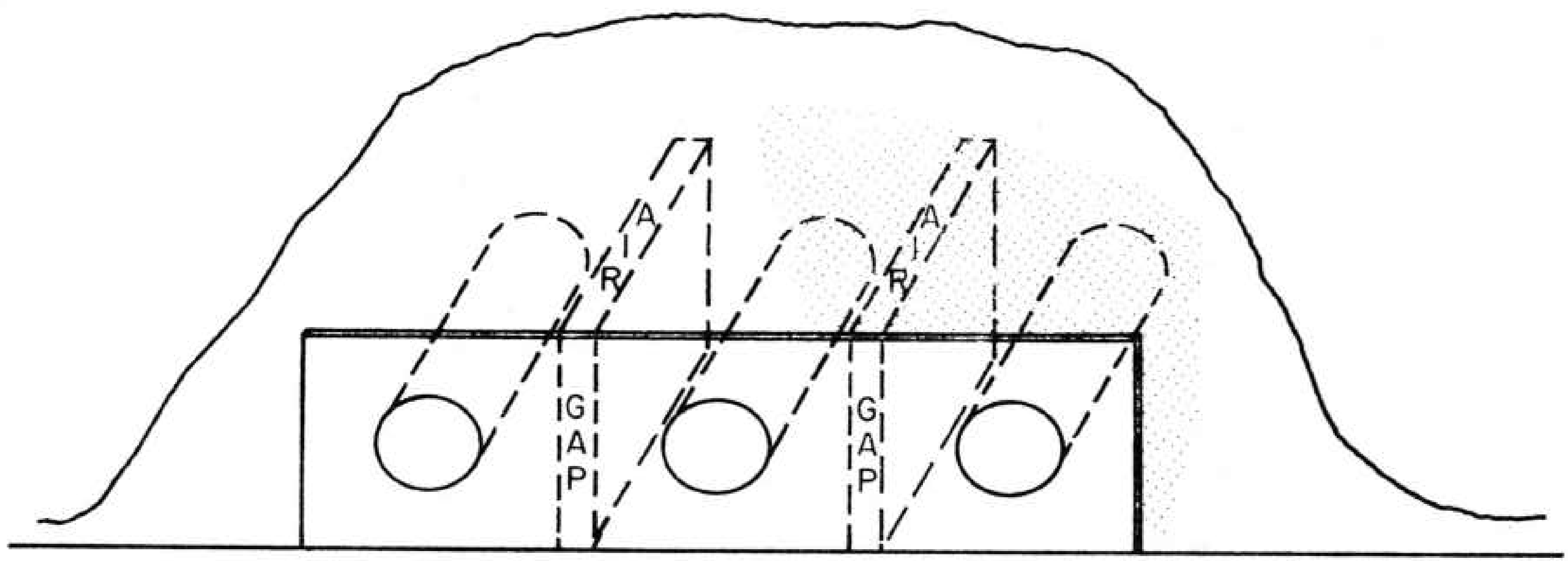
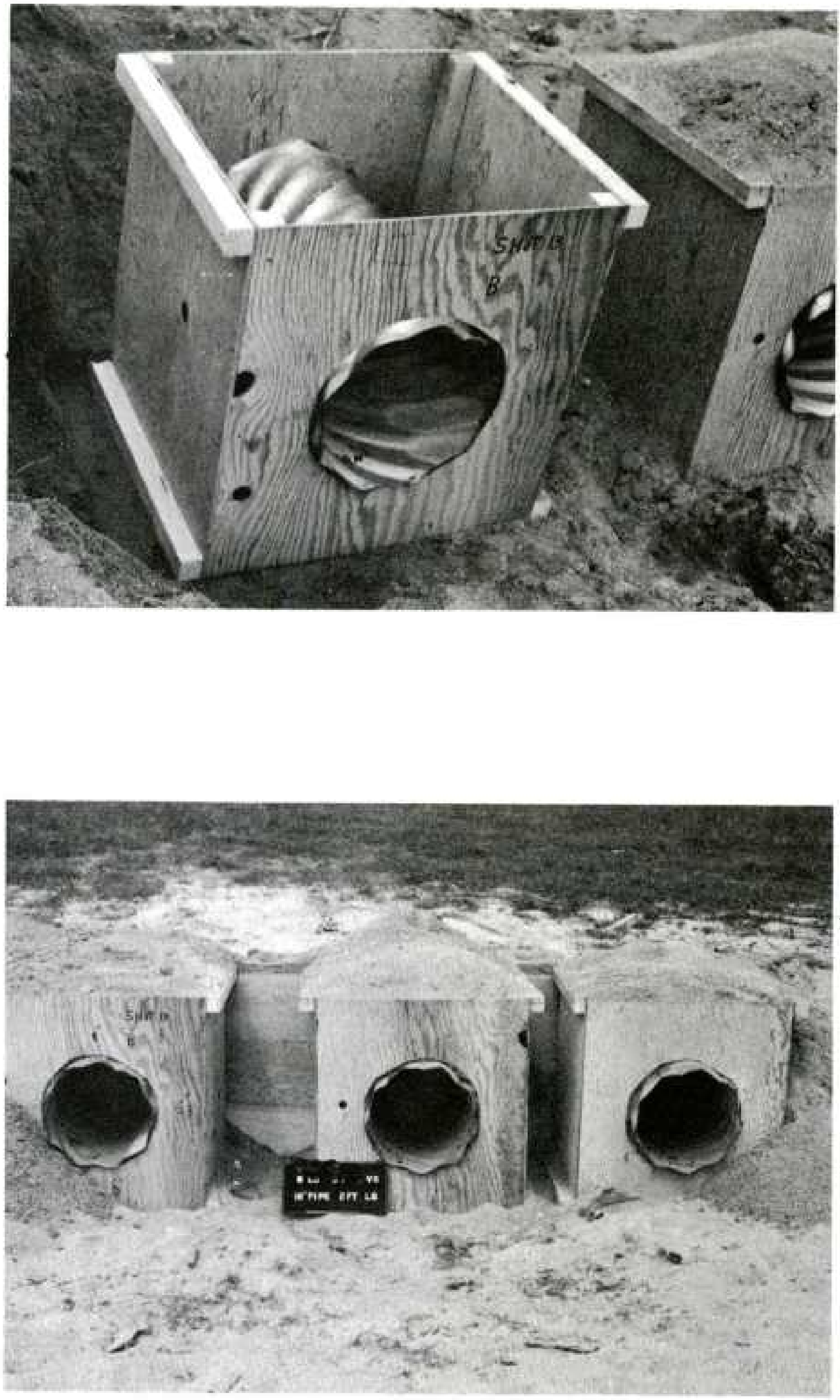


Figure 3. Test Setup: Sand-Air-Sand Barriers Test No. 13



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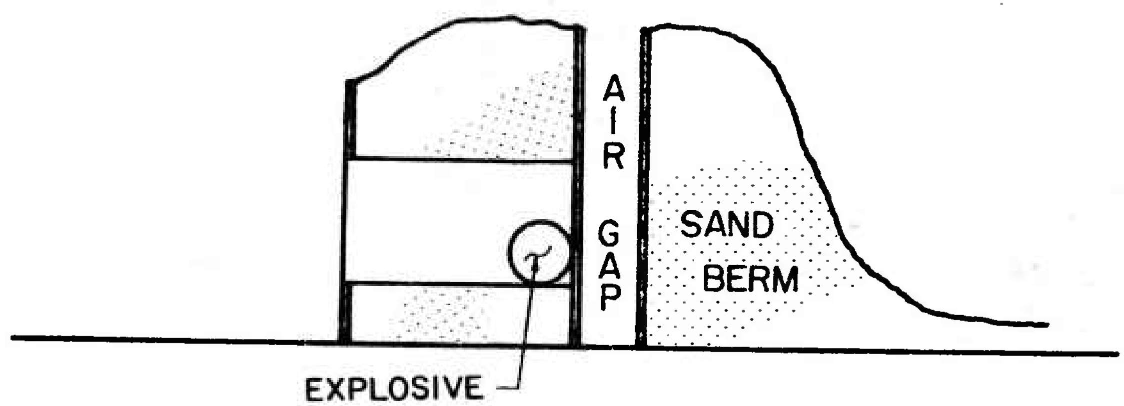


Figure 5. Test Setup - Improved Venting Test No. 21

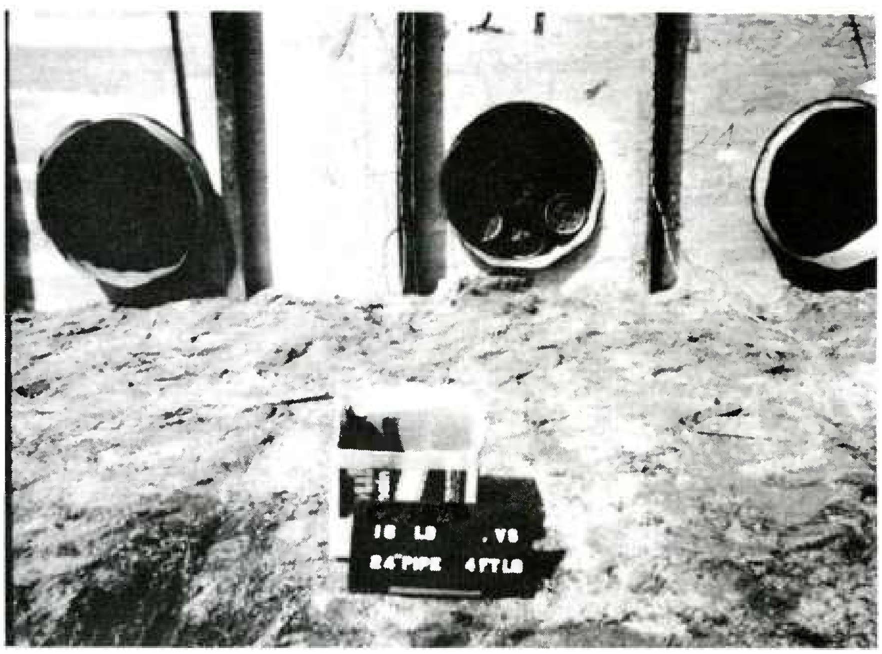


Figure 6. Test Setup - Restricted Venting Test Nos. 22 and 25

Table 1. Donor-Acceptor Test Results for Corrugated Steel Pipe

TEST NO.	PIPE DIAMETER	PIPE LN	HE WEIGHT LBS	HE WEIGHT (KG)	ACCEPTOR A SPACING (DIA)	ACCEPTOR A DEFORMATION	ACCEPTOR B SPACING (DIA)	ACCEPTOR B DEFORMATION	REMARKS
1	0.5 ft (15.24 cm)	1.0 ft (30.48 cm)	0.25	(0.1134)	0.5	5.6 in (14 cm) F[1] 5.0 in (13 cm) R[2]	1.0	ND[3]	See Footnote 4
2			0.50	(0.2268)	1.0	5.8 in (15 cm) F 5.5 in (14 cm) R	1.5	ND	
3			0.75	(0.3402)	1.5	5.8 in (15 cm) F 5.0 in (13 cm) R	2.0	ND	
4			4.0	(1.8144)	4.0	ND	5.0	ND	
5			8.0	(3.6288)	4.0	2.5 in (6 cm) F	5.0	5.5 in (14 cm) F 5.5 in (14 cm) R	
6			8.0	(3.6288)	4.0	0 in (0 cm) F 0 in (0 cm) R	5.0	1.5 in (4 cm) F 0.8 in (2 cm) R	Overhead sand cover depth increased from one to four diameters.
7		2.0 ft (61 cm)	0.5	(0.2268)	1.0	See Remarks	1.5	ND	Slight crushing observed in center of Acceptor A.
8			0.5	(0.2268)	1.0	ND F 4.0 in (10 cm) R	1.5	ND	
9	1.0 ft (30.5 cm)	2.0 ft (61 cm)	4.0	(1.8144)	0.5	6.5 in (17 cm) F 1.0 in (3 cm) R	1.0	10.2 in (26 cm) F 5.0 in (13 cm) R	
10			2.0	(0.9072)	0.5	11.4 in (29 cm) F 5.5 in (14 cm) R	1.0	ND	
11			4.0	(1.8144)	1.0	8.8 in (22 cm) F 2.2 in (6 cm) R	1.5	ND	
12			8.0	(3.6288)	1.5	7.5 in (19 cm) F 3.2 in (8 cm) R	2.0	11.5 in (29 cm) F 10.0 in (25 cm) R	
13			12.0	(5.4432)	1.0 Sand- -0.5 Air	4.5 in (11 cm) F 1.0 in (3 cm) R	1.5 Sand- -0.5 Air	3.5 in (9 cm) F 2.6 in (7 cm) R	

Table 1. Donor-Acceptor Test Results for Corrugated Steel Pipe (Continued)

TEST NO.	PIPE DIAMETER	PIPE LN	HE WEIGHT LBS	(KG)	ACCEPTOR A SPACING (DIA)	ACCEPTOR A DEFORMATION	ACCEPTOR B SPACING (DIA)	ACCEPTOR B DEFORMATION	REMARKS
14	1.0 ft (30.5 cm)	2.0 ft (61 cm)	8.0	(3.6288)	1.0 Sand- -0.5 Air	5.5 in (14 cm) F 1.0 in (3 cm) R	1.0 Sand- -1.0 Air	6.0 in (15 cm) F 3.0 in (8 cm) R	
15			6.0	(2.7202)	1.0	6.8 in (17 cm) F 1.5 in (4 cm) R	1.5	9.8 in (25 cm) F 6.4 in (16 cm) R	
16			6.75	(3.0618)	0.5	16.5 in (42 cm) F 7.2 in (18 cm) R	1.0	ND	
17	1.5 ft (45.7 cm)	3.0 ft (91.4 cm)	13.5	(6.1236)	1.0	ND R 11.0 in (28 cm) F	1.5	16.0 in (41 cm) F 14.0 in (36 cm) R	
18			13.5	(6.1236)	2.0	ND	2.5	ND	
19			16.0	(7.2576)	0.5	22.5 in (57 cm) F 2.0 in (5 cm) R	1.0	22.8 in (58 cm) F 17.5 in (44 cm) R	
20			25.0	(11.34)	1.5	21.0 in (53 cm) F 6.0 in (15 cm) R	2.0	ND	
21	2.0 ft (61 cm)	4.0 ft (122 cm)	16.0	(7.2576)	0.5	23.0 in (58 cm) F 6.0 in (15 cm) R	1.0	ND	Six inch (15 cm) air gap between normally closed end of pipe and sand berm.
22			16.0	(7.2576)	1.0	21.8 in (55 cm) F 3.0 in (7.6 cm)R	1.5	ND	Donor contained four 155 mm propellant charge cans.
23			47.5	(21.546)	3.0	ND	4.0	ND	
24			47.5	(21.546)	2.0	22.0 in (56 cm) F 18.7 in (47 cm) R	2.5	ND F 19.0 in (48 cm) R	
25			25.0	(11.34)	2.0	ND F 22.8 in (58 cm) R	2.5	ND	Donor contained four 155 mm propellant charge cans.

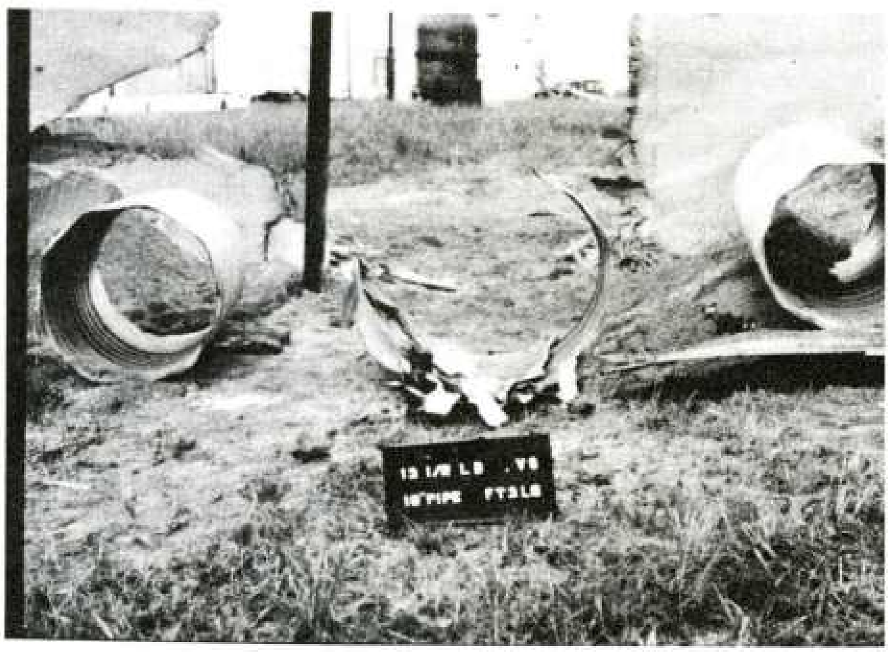
1. Shortest distance between the sidewalls at the front or open end of the damaged pipe.
2. Shortest distance between the sidewalls at the rear or closed end of the damaged pipe.
3. No Damage.
4. The HE charge was positioned in the center of the donor pipe in Tests 1, 2, 3, and 7. The HE charge was positioned in the rear or closed end of the donor pipe in the remaining tests.

Test No. 10

Test No. 11

Figure 7. Test Results

Test No. 17



Test No. 18

Figure 8. Test Results

Test No. 20

Test No. 24

Figure 9. Test Results

D. Improved Venting

Providing an opening at the normally closed ends of the pipes to improve venting, see Figure 5, reduced the safe separation distance requirement by approximately one half pipe diameter. Compare Tests 19 and 21.

E. Restricted Venting

Positioning four sand-filled 155 cm propelling charge cans between the explosive charge and the normally open end of the donor pipe, to restrict venting, increased the safe separation distance by approximately one quarter of a pipe diameter. Compare Tests 19 and 22 and Tests 20 and 25.

F. Increased Top Cover

Increasing the overhead sand cover depth from one to four pipe diameters increased the safe separation distance requirement by an estimated one pipe diameter. Compare Tests 5 and 6.

IV. DISCUSSION

In general, the test results offered few surprises and with the exception of the performance of the sand-air-sand barriers, data trends could have been predicted a priori in qualitative terms.

The relatively poor performance of the sand-air-sand barriers was unexpected. Unfortunately, the point at which the performance of sand-air-sand barriers equal or exceed those of all sand barriers cannot be predicted with the limited data base generated in this series of tests. However, the decision to employ sand-air-sand barriers, based on performance, must take into consideration the relative construction and maintenance costs, quantity-distance restrictions and the type of ordnance to be stored.

A cursory examination of the test results, for the standard test setup, show that the safe separation criteria established for the small diameter pipe cannot be used to predict safe separation distances for the large diameter pipe in terms of a simple explosive charge weight to pipe volume ratio. As expected, the smaller diameter pipes appear stronger than the larger diameter pipes on a charge weight to volume ratio basis. This can be accounted for in part by the fact that the pressure required to deform (crush) a steel pipe with a constant wall thickness decreases as the diameter of the pipe increases.

The results of a regression and discriminant analysis of the test results can be used to either design a new facility or evaluate the safety of an existing facility. The (1) regression and (2) discriminant equations are:

(1) Distance (inches) = 15.48 + 4.524 (LOC) - .009 (Ratio) + 1.156 (Wgt) - 11.675 (DAM)

Where:

LOC = 1 for HE charge in center of pipe, 2 for HE charge in rear of pipe

$$\text{RATIO} = \frac{\text{Volume of Pipe (in.}^3\text{)}}{\text{HE Wgt (lb)}}$$

Wgt = HE Wgt. (lb)

DAM = 1 for damage, 0 for no damage

(2) $$\text{RES} = -.624 + .1618\ (\text{SD}) - 1.312\ (\text{LOC}) + .00178\ (\text{Ratio}) - .178\ (\text{Wgt})$$

Where:

RES = positive for no damage, negative for damage

SD = separation distance in inches

LOC = 1 for HE charge in center of pipe, 2 for HE charge in rear of pipe

$$\text{RATIO} = \frac{\text{Volume of Pipe (in.}^3\text{)}}{\text{HE Wgt. (lb)}}$$

Wgt = HE Wgt (lb)

A comparison of the observed and predicted safe separation distances are presented in Figure 10. The predicted values were generated using both the regression equation (equation 1 - no damage case) and the discriminant equation (equation 2 where RES is set to zero - solve for SD).

In actual practice, storage facilities using sand covered pipes present potential debris and overpressure hazards that will be directional. Additional testing will be required to identify these hazards quantitatively before a safe site plan can be prepared.

V. CONCLUSIONS

Conservative estimates of the safe separation distances between sand covered steel pipes, designed to store explosive ordnance items, have been established empirically via donor acceptor tests. Limited test data are also available on the influence of venting, explosive charge position, top cover depth and the effectiveness of sand-air-sand barriers.

While the results of this series of tests can be used to estimate the distance between pipes required to localize damage in the event that the explosive ordnance items in one pipe detonate en masse, they do not identify debris and overpressure hazards. This will require additional testing.

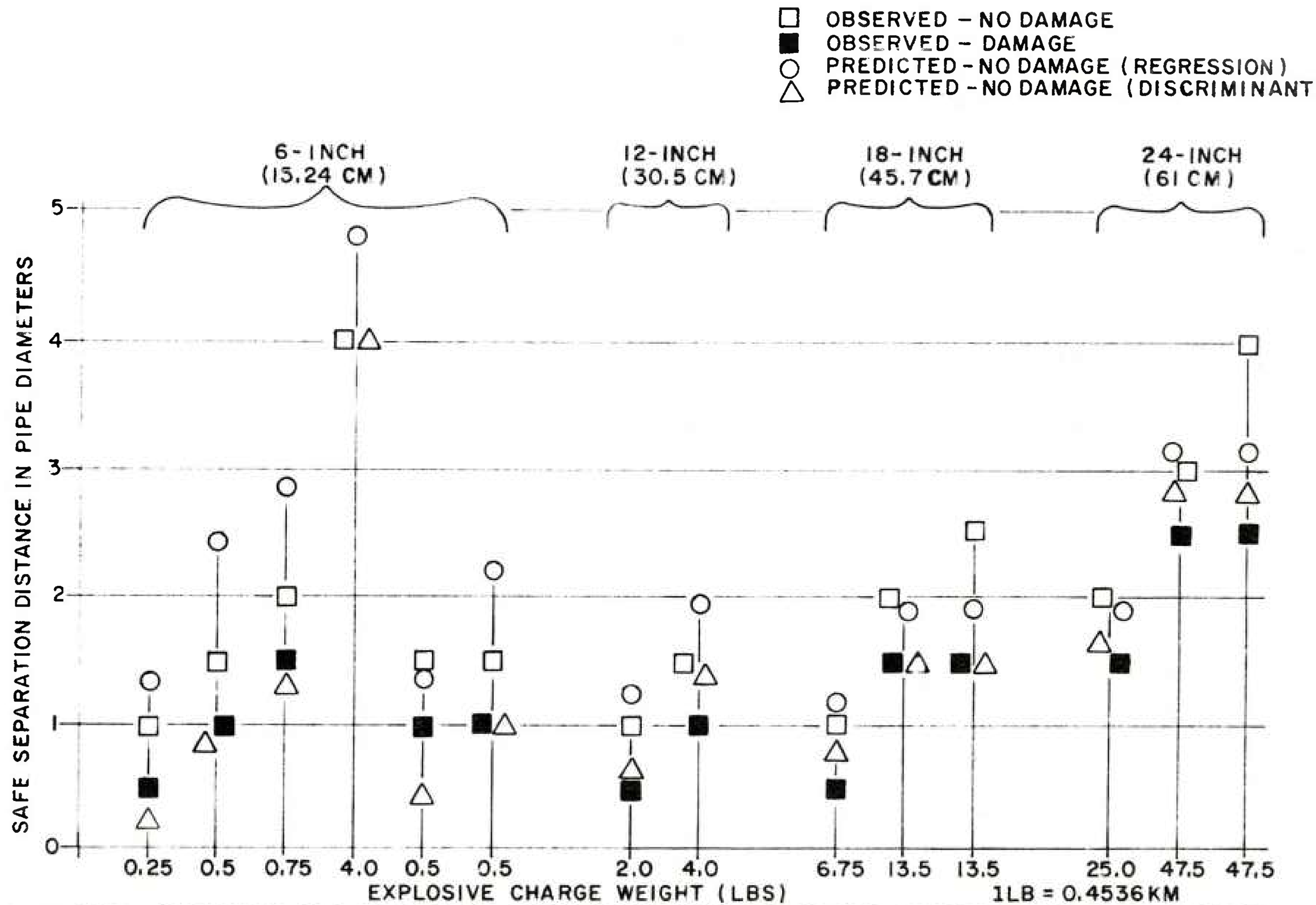


FIGURE 10. OBSERVED AND PREDICTED SAFE SEPARATION DISTANCES VERSUS EXPLOSIVE CHARGE WEIGHT.

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